Abstract

The design of Solid Rocket Motor (SRM) grains has traditionally been constrained by manufacturing limitations and by the assumption of spatially uniform ballistic properties or discrete variations of the composition, as in dual-thrust grains. Recent advances in additive manufacturing technologies have introduced new opportunities for the realization of complex three-dimensional grain geometries and locally tailored material characteristics, enabling novel thrust modulation leverage. In addition to increased design flexibility, additive manufacturing may also offer potential advantages at process level, such as reductions in manufacturing complexity and cost, improved repeatability, and a mitigation of risks related to the handling of toxic or hazardous propellant additives. These developments require advanced numerical tools capable of accurately simulating grain regression and internal ballistics in the presence of non-uniform burning behavior. This thesis presents a numerical simulation and inverse design framework for the analysis and optimization of solid rocket motors with complex grain geometries and spatially varying burning rates. The proposed approach is based on the Level Set Methods to implicitly represent the evolving burning surface during grain regression, providing a flexible and robust description of arbitrary three-dimensional configurations. The instantaneous geometry representation is coupled with a zero-dimensional chamber formulation to predict pressure–time histories under non-uniform ballistic conditions. Different strategies for distance field initialization and surface evolution are investigated. To enable efficient inverse design and reduce computational costs, surrogate modeling techniques are introduced to approximate the motor pressure response as a function of geometric and ballistic parameters. These surrogates are integrated within stochastic optimization algorithms, allowing the exploration of large design spaces that would otherwise be computationally prohibitive. A linear viscoelastic mechanical model is included to validate the structural performance of the optimized grain and to compare classical and non-uniform grain configurations. The proposed methodology is validated through a set of test cases, ranging from canonical grain configurations to motors characterized by spatially varying burning rates. The framework is further applied to real life application, demonstrating that different combinations of grain geometry and ballistic distributions can achieve comparable performance levels when appropriate design flexibility is introduced. Overall, the results highlight the potential of combining additive manufacturing technologies with advanced numerical simulation and inverse design techniques to expand the performance envelope of solid rocket motors. By enabling controlled thrust shaping and performance tailoring through geometric and material design, the proposed framework provides a solid foundation for future developments in flexible, high-performance solid propulsion systems.